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Design and implementation of a low cost RFID track and trace system in a learning factory

Louis Louw[a]*, Mark Walker[a]

[a]Industrial Engineering Department, Stellenbosch University, Joubert Street, Stellenbosch, 7600, South Africa

Abstract

The factories of the future will make use of actuators, sensors and cyber-physical systems (CPS) to provide an environment in which human beings, machines, and resources will communicate as in a social network. In such a network, communication between various "objects" relay the current state of the physical world. Business decisions are made using the information and it is therefore critical that this information is accurate and in real-time. Information flow is a key enabler of such future factories. Industrial engineers, as designers and improvement agents of such factories of the future, will need to develop better skills in various aspects of data analytics and information communication technologies. This paper describes the development and implementation of a low cost RFID track and trace system (by students) for application in a Learning Factory for teaching undergraduate industrial engineering students key concepts related to Industry 4.0 and "smart factories". The benefit of this system is not only a demonstrator to be used in the Learning Factory, but also can be used to teach students in a "learning by doing" fashion critical skills related to real time tracking in a manufacturing environment. The system also demonstrates potential low cost implementation of such technologies in SME's.

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Keywords: RFID; Track and Trace; Industry 4.0; Learning Factories

1. Introduction

Today we stand on the cusp of the Fourth Industrial Revolution, one which promises to marry the worlds of production and network connectivity in an "Internet of Things" [1]. No longer do machines just produce products, the

* Corresponding author. Tel.: +27 21 808 4448.
E-mail address: louisl@sun.ac.za

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products communicate with the machine to tell it exactly what to [1]. Key elements of this fourth industrial revolution (or Industrie 4.0 as coined by Germany) include the digitization and real-time-oriented integration of the various components of the value-adding system [2]. Hermann [3] set out to provide a clear definition of Industry 4.0 based on a comprehensive literature review. He defines Industry 4.0 as follows: "Industry 4.0 is a collective term for technologies and concepts of value chain organization. Within the modular structured Smart Factories of Industry 4.0, cyber physical system (CPS) monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the IoT (Internet of Things), CPS communicate and cooperate with each other and humans in real time. Via the IoS (Internet of Services), both internal and cross- organizational services are offered and utilized by participants of the value chain." This definition mentions the four major components of Industry 4.0: CPS, IoT, IoS and Smart Factories. CPS enables the fusion of the virtual world with the physical world [4]. IoT allows things and objects, such as RFID tags, sensors, actuators, mobile phones etc to communicate and interact within a smart factory [5]. The idea behind the IoS is to use the internet for new ways of value creation in the service sector [6]. A key enabler of the CPS, IoT, IoS and Smart Factories is cloud computing, which is also transforming the conventional product-oriented manufacturing business model into a service-oriented one [7]. The requirement for mass customization under Industrie 4.0 however brings significant complexity, which makes the design and evaluation of product-service systems challenging [8].

RFID has been identified as an important technology for enabling the real-time-oriented integration/communication of the various components of the value-adding system in an Industry 4.0 context [9]. This paper describes the development and implementation of a low cost RFID track and trace system (by students) for application in a Learning Factory for teaching undergraduate industrial engineering students key concepts related to Industry 4.0 and "smart factories". The benefit of this system is not only a demonstrator to be used in the Learning Factory, but also can be used to teach students in a "learning by doing" fashion critical skills related to real time tracking in a manufacturing environment. The system also demonstrates potential low cost implementation of such technologies in small-and-medium sized enterprises (SME's).

2. Track and trace technologies

Tracking and tracing are important concepts in global supply chain and logistics networks [10]. Two key technologies being used in supply chain environment for tracking and tracing are barcodes and Radio-frequency identification (RFID). RFID is a modern automatic identification and data capture (AIDC) technology that is slowly gaining more acceptance in the supply chain today. RFID technology allows objects to be identified without line of sight and with a greater reading distance compared to barcode technology [11], [12]. RFID tags can hold much more data and support a much larger set of unique IDs than barcodes [13]. In addition, RFID systems can discern many tags in a single area at once without human assistance, unlike their barcode counter parts. For electronic track and trace technology to compete with traditional barcode technology they must either be equally as cheap or add enough value to an organization to recover the cost elsewhere [14]. The main reason RFID technology is becoming more popular, has been its drastic decrease in price over the years. With the technology reaching a critical point which could see its larger scale adoption in the consumer retail section [14].

According to, Sarma et al. [15], all RFID systems are comprised of three components: the tag or transponder, the reader, as well as the data processing subsystem comprising of middle-ware and internal databases. Tags at the highest level, can be divided into two classes namely active and passive tags. Active tags have power a source integrated into the tag and actively send a Radio Frequency (RF) signal to communicate with the RFID reader. Passive tags on the other hand are powered through interrogation signals from the reader and communicate through either near or far field communication [15].

Each RFID system operates at a given frequency range. This frequency range determines the system's capabilities and limitations. Consequently, the higher the frequency range the shorter the wavelength, the harder it becomes for the RF to pass over obstacles and reach the receiver. In other words, the higher the frequency, the higher the interference. The radio spectrum is part of the electromagnetic spectrum from 3Hz to 3000GHz. Therefore, the different types of tags can be placed into three distinct frequency ranges: Low Frequency, High Frequency, and Ultra High Frequency tags (these depend on the country).

3. The Stellenbosch Learning Factory

The Stellenbosch Learning Factory (SLF) was established in 2015 as a place where students can “learn by doing”. The initial focus of the learning factory was to teach students lean principles found in typical manufacturing environments. The SLF aims to demonstrate these lean principles through the manufacturing of small model trains, inspired in colour and make-up by the South African Metrorail. The current layout of the SLF is shown in Fig.1. The SLF is moving toward the implementation of Industry 4.0 concepts, with the goal of illustrating a realistic model of a typical Smart Factory. Tracking and tracing with sensors for collecting data was identified as first step towards the development of a smart factory. Due to the read and write capabilities of RFID, it was selected as the methodology for enabling tracking and tracing.

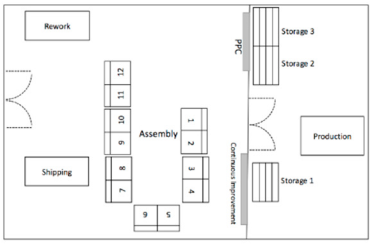

Fig.1. The SLF layout.

4. Design approach

The RFID based track-and-trace system was developed by two students in the learning factory as part of a final year project. The aim was therefore to teach the students specific skills related to the design of integrated systems in a production environment, while at the same time ending with a working system that can be used in the SLF. An agile modelling approach was used to achieve the objectives for the development of the RFID based track-and-trace system. The approach was incremental and involved interaction between the SLF management and the students as designers. It was decided that a prototyping method would be used with the focus of creating an operational model.

5. RFID system development

5.1. Database development stage

Firstly, the system requirements were clearly defined and analyzed to determine the specific data required. The RFID system will be required to display several Key Performance Indicators (KPIs) on a monitor at each workstation, as well as a monitor for the KPIs related to the complete assembly line. In order to calculate the required KPI’s, the following data requirements were identified:

- Each train will require a specific chassis ID. This will be represented on the RFID tags Unique Identification number (UID). The chassis ID will identify the type of train (Cabin or Driver), the order number it is associated with, and the train number in the order.
- A Time-stamp will need to be logged when a RFID tag is scanned at the different stations. This Time-stamp will need to be associated with the chassis ID.
- A status will be required. This status must be associated with each chassis ID.
- A Station ID will need to be associated with each train’s chassis ID. Thus, the position of a specific train chassis within the system will be shown.
- A due date of each order will need to be associated with the chassis ID to calculate percentage order fulfillment.

Database design started with a conceptual data model in order to conceptualize the flow, the processes and the transformations of data as it moves throughout the system. The conceptual data model produces a specification of a logical schema, which determines the specific type of database system that is required. As a first step in the conceptual model, Entity Relationship Diagrams (ERDs) were constructed. Once the relationships between the different entities was understood, data dictionaries were used to describe the attributes and records of the entities.

5.2. Hardware selection

A master/slave computing concept was used in this project. The master/slave concept reduces the processing load on a single computer, by distributing the processing load across smaller, less powerful microcontrollers. This technique allows for the design of a cost-effective system, as the less processing power required, the cheaper the hardware. The following requirements had to be considered:

- Several microcontrollers will be communicating with a central database;
- The central database will be processing the data collected and will display various KPI's enabling vertical integration of the manufacturing system from field level to management level; and
- A network, or "IoT" had to be created for the microcontrollers to communicate over, (this was represented by a WIFI Router).

Firstly, a microcomputer that will act as the "master" computer and run the data processing subsystem was selected by comparing several alternatives. Secondly, a "slave" unit were selected by comparing various microcontrollers. The slave unit collects the data from the RFID reader and transfer it via an internal network to the master computer. The primary selection criteria was to find a microcomputer that was easy to interface with, preferably running Linux, has a Quad-Core processor, WIFI-enabled, low cost, and easily available in South Africa. A thorough investigation of various microcomputers was completed. The Raspberry Pi model 3B was found to meet the primary selection criteria. It is the most cost effective of the microcomputers compared.

The slave microcontroller unit (MCU) is used to collect the data from various stations. In effect it enables the RFID reader to connect via WIFI, in order to send the RFID tag's necessary information. The microcontroller, once again, will not require much processing capability as the data acquisition process is not very demanding. According to, Espressif Systems [16], the most popular chip that is used to demonstrate IoT applications is the ESP8266 MCU. Therefore, several open source development boards that make use of a ESP8266 System-On-Chip's (SoC) were investigated. The primary selection criteria for the microcontroller includes the following: the microcontroller must be easy to interface with, have a high number of GPIO pins, low cost and easily available in South Africa. A thorough investigation of various microcontrollers was completed. It was found that the NodeMCU V3 meets the primary selection criteria, and more importantly, it is the most cost effective of the microcomputers compared.

There is no such thing as a typical RFID tag for each operating environment. The read range is a trade off between several engineering factors such as: the frequency of the RFID system operation, the power of the reader and the level of interference created from other RF devices. For this project it was decided that a high frequency (13.56MHz) tag would be used, providing the most cost- effective option.

5.3. Software Selection: Relational Database Management Systems

There are several primary requirements for the Relational Database Management System (RDMS). These include: the ability to be installed on Linux (the operating system of the Raspberry Pi), the software must be open source, the software must be able to execute Structure Query Language (SQL) statements and must be able to execute triggers to manipulate the data. As a result of these requirements several database engines were not suitable for application in the SLF. Various database engines' properties and features were compared. It was decided that MariaDB would be used on the grounds of its: ease of availability, ease of use, better performance compared to MySQL and its popularity amongst users.

In conjunction with the data processing software, business intelligence (BI) software is required to create a real-time dashboard of various KPI's, derived from the data processing subsystem. The primary requirements for the BI software are: compatibility with MariaDB, the ability to build a custom dashboard with a real-time refresh rate (refresh-rate under 10 seconds), and the ability to execute SQL statements. InfoCaptor designed by Rudrasoft met the initial requirements and was selected for the BI component.

5.4. RFID system development

A bottom-up approach was taken when implementing the RFID system. This approach was used because it was necessary to start with the "backbone" of the system, the database, to be hosted on the Raspberry Pi 3B. The first step in setting up the data processing subsystem was to create a local web server. The most popular open source web server for Linux operating system is a LAMP server. LAMP is an archetypal model of web-service stacks, named as an acronym of the names of its original four open-source components: the Linux operating system, Apache as a web Server, MariaDB as the RDBMS, and the PHP programming language as the object-orientated scripting language.

After testing that the correct data was being manipulated by each reader and the train's chassis ID was being correctly written to the tag, the following step was to design the real-time dashboards in InfoCaptor. In total, 14 dashboards were designed to show the required KPI's. In addition, a system-overview dashboard was developed that displays the KPIs for the whole assembly line as well as the KPI's of each work station. Figure 2 shows an overview diagram that summarizes and help to visualize the flow of data between the various hardware and software.

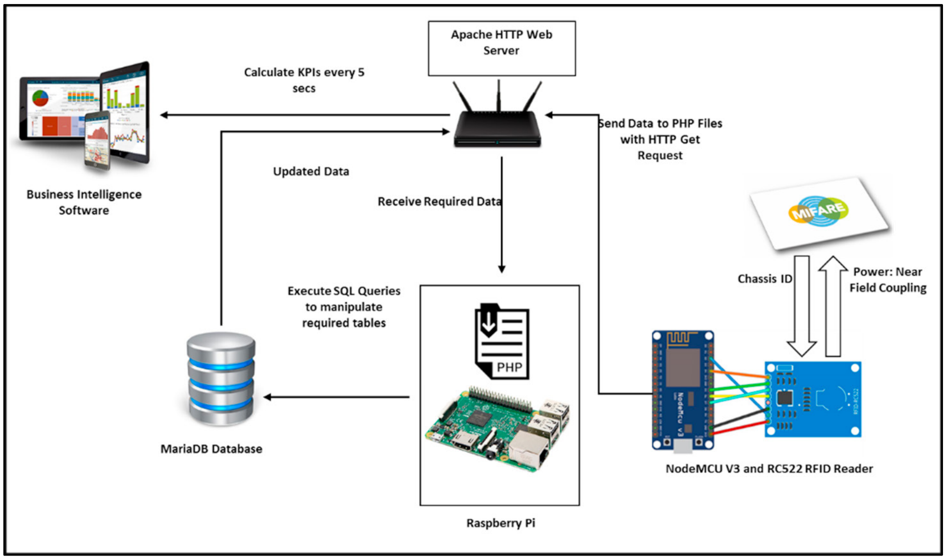

Fig. 2. The basic functioning of the SLF RFID system

5.5. Total system integration

Once the code had been written and the dashboards constructed, the system was implemented in the SLF. Following this, a total system's test was performed, to determine if the requirements of the system were met.

6. Conclusion

The main objective of this project was to create a cost-effective RFID system for use in a learning factory. This limited the choice of hardware and software to open-source components. With open-source components there are many advantages, such as an online community from which advice can be easily accessed but it also comes with many disadvantages such as a lack of features and processing power. To highlight just how cost effectively this system was developed a comparison was done to the cost of an off the shelf system. The results of the comparison are shown in Table 1.

Table 1. Cost estimation comparison of the SLF system vs an industry example

	Quantity	SLF RFID System	Industry Estimate (RFID)
RFID Tags	30	€15	€1577000
RFID Readers	14	€291	€4813
Monitors	13	€727	€727
Back-End Software (including database)	1	Open Source	€12 815
Raspberry Pi and WI-FI	1	€142	Included above
Site Survey, Labour, Installation	1	Free	€4313
Total Estimate		€1175	€22 683

Several key challenges were faced during the project. These included: selecting the hardware components, coding the microcontrollers to connect to the WI-FI, getting the PHP files to execute correctly on command of the microcontrollers, understanding the block structure of the RFID tags, determining how to limit the number of queries executed by the dashboards so as to avoid a database query overload. The project however demonstrated that an effective, working system can be developed at low cost for use in a learning factory. Valuable systems development skills were also gathered by the students as part of the project, which demonstrated the value of a “learning by doing” approach. The developed RFID system will be used in the SLF as a first step towards further development of a “smart factory”.

References

[1] W. Fue, Industrie 4.0, Germany Trade and Invest, (2014) 1-20.

[2] R. Neugebauer, S. Hippmann, M. Leis and M. Landherr, Industrie 4.0 - From the Perspective of Applied Research, Procedia CIRP, 57 (2016) 2-7.

[3] M. Hermann, T. Pentek and B. Otto, Design principles for industrie 4.0 scenarios, Proceedings of the Annual Hawaii International Conference on System Sciences, (2016) 3928-3937.

[4] L. Monostori, Cyber-physical production systems: Roots, expectations and R&D challenges, Procedia CIRP, 17 (2014) 9-13.

[5] L. Atzori, A. Iera and G. Morabito, The Internet of Things : A survey, Computer Networks, 54 (2010) 2787-2805.

[6] D. O. Alistair Barros, Handbook of Service Description, D. O. Alistair Barros, Ed., Springer, (2012).

[7] D. Mourtzis and E. Vlachou, Cloud-based cyber-physical systems and quality of services, The TQM Journal The TQM Journal, 28 (5) (2016), 704-733.

[8] D. Mourtzis, S. Fotia and N. Boli, Complexity within Mass Customization and Industry 4 . 0 Environment, 23rd ICE/IEEE International Technology Management Conference, (2017) 1207-1213.

[9] S. Gill, The role of RFID in the smart factory, Control Engineering, 62 (6) (2015) [np].

[10] A. Shamsuzzoha and P. Helo, Real-time tracking and tracing system: Potentials for the logistics network, Proceedings of the 2011 International Conference on Industrial Engineering and Operations Management, January (2011) 242-250.

[11] S. A. Joseph and N. J. Joby, Analyzing RFID Tags in a Distributed Environment, Procedia Technology, 24 (2016) 1483-1490.

[12] A. Akbari, S. Mirshahi and M. Hashemipour, Comparison of RFID system and barcode reader for manufacturing processes, Canadian Conference on Electrical and Computer Engineering, June (2015) 502-506.

[13] T. Lotlikar, R. Kankapurkar, A. Parekar and A. Mohite, Comparative study of Barcode, QR-code and RFID System, International Journal of Computer Technology and Applications, 4 (2013) 817, 2013.

[14] M. Kaur, M. Sandhu, N. Mohan and P. S. Sandhu, RFID Technology Principles, Advantages, Limitations & Its Applications, International Journal of Computer and Electrical Engineering, 3 (2011) 1793-8163.

[15] S. E. Sarma, S. A. Weis and D. W. Engels, RFID systems and security and privacy implications, Cryptographic Hardware and Embedded Systems, 252 (2002) 454-469.

[16] Espressif Systems, ESP8266EX Datasheet, Espressif Systems Datasheet, (2015) 1-31.